CNST Progress Report
and
Recent Highlights in Nanotechnology at NIST

Robert Celotta, CNST, Acting Director

VCAT Nanotechnology Subcommittee Meeting

December 11, 2007

(For further information see: http://cnst.nist.gov)

Outline

- CNST Progress Report
  - Brief Description of CNST
  - Strategic Planning
  - Highlights
  - Challenges
- NIST Nanotechnology Highlights
- Appendix – Strategic Planning Process

The Center for Nanoscale Science and Technology

Progress Report

CNST Mission

- CNST:
  - provides **measurement methods**, standards and technology to support all phases of nanotechnology development from discovery to production,
  - develops and maintains a national shared use facility, **the Nanofab**, with state-of-the-art, nanoscale fabrication and measurement capabilities
  - applies a **multidisciplinary** approach to problem solving that involves partnering with industry, academia, and other government agencies,
  - serves as a hub to **link the external nanotechnology community** to the vast measurement expertise that exists within the NIST Laboratories, and
  - helps to **educate** the next generation of nanotechnologist.

CNST - Desired Characteristics

- **Multidisciplinary**
  - Problem, rather than discipline, oriented
- **Agile**
  - Able to rapidly shift program emphasis
- **Focus on Measurement Science**
  - Provide measurements and methods not available elsewhere
- **Active and stimulating intellectual atmosphere**
  - Learning, teaching, and interacting with colleagues commonplace
- **Research Staff**
  - Carefully selected staff that shares the vision and measurement science mission of NIST, is highly collaborative, and has the autonomy and freedom to accomplish the mission
- **Research Management**
  - "Walk-around" management style focusing on achievements, opportunities, and problem solving
- **Program execution without undue delay**
  - Substantial operational funding level and strong technical support
- **Low barriers to collaboration**
  - We are easy to work with
- **AML Location**
  - We leverage our location to offer unique capabilities to our partners.

CNST Structure

- The CNST consists of a Research Program and the CNST Nanofab
  - The Research Program
    - Enabling nanotechnology with measurement solutions
  - The Nanofab
    - A National Shared Use Facility with state-of-the-art ***measurement*** and ***fabrication*** capabilities

CNST Organizational Chart

Center for Nanoscale Science and Technology
Robert Celotta, Acting Director
Ted Vorburger, Acting Deputy Director

Ladonna Lauren, Senior Management Advisor
Karen Haugh, Administrative Officer
Joyce Waters, Administrative Assistant
Vacant, Administrative Assistant

The Nanofab

Nanofab Operations Group
Gerard Henein, Leader
Kathy Jones, Admin. Asst.

The Research Program

Electron Physics Group
Jabez McClelland, Leader
Denise Rogers, Admin. Asst.

Nanofabrication Research Group
J. Alex Liddle, Leader
Key'una Beasley, Admin. Asst.

Future Group

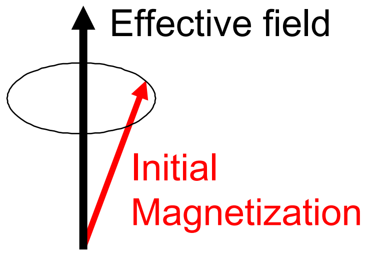
December 10, 2007

Strategic Planning - Goals

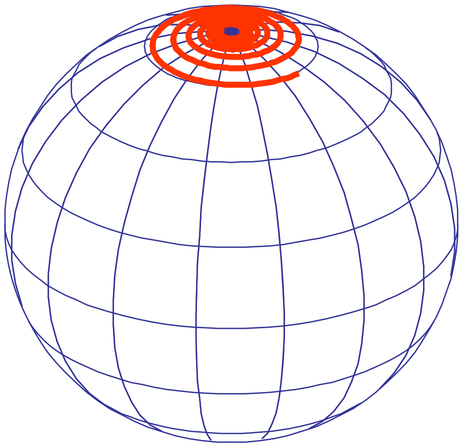
- Nanofab
  - Establish Nanofab as a world-class facility
  - Greatly broaden the scope and capabilities of the Nanofab
  - Expand the Nanofab user base
- Research Program
  - Determine measurement needs
  - Determine major program areas
  - Determine core competence requirements
  - Recruit the best and the brightest (who are enthused by our mission)
  - Establish strategic partnerships
- Infrastructure
  - Establish an administrative staff configured for efficiency and agility
  - Establish and provide for continuous refinement of operational policies
  - Acquire and provision the space necessary to operate

Research Program Highlight
Quantitative calculation of damping in transition metals

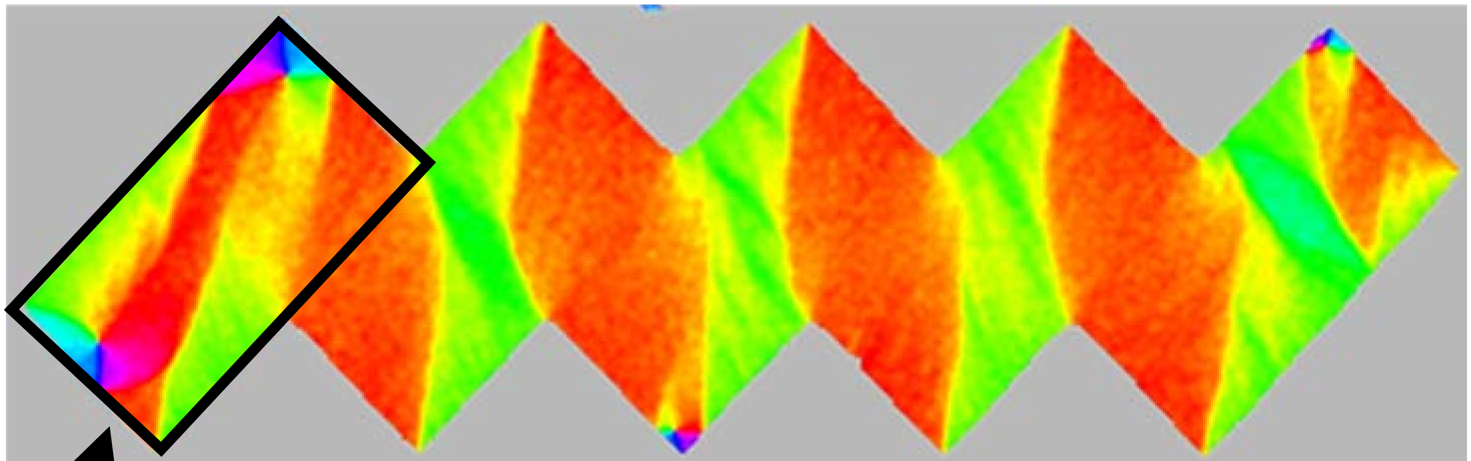
- Magnetization damping determines performance of magnetic nanodevices
- The damping mechanisms have not been established
  - There is no way to calculate the damping rate of a given material or nanostructure.
- We have computed the damping rate for Fe, Co, and Ni, demonstrating
  - quantitative agreement with temperature dependent measurements,
  - the dominant mechanism of damping, and
  - the ability to compute it.



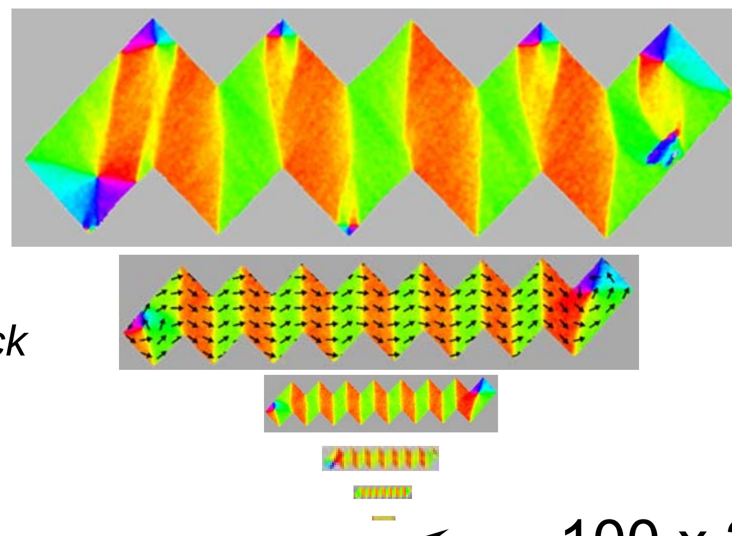
Damped motion



Research Program Highlight
Magnetization vs. size – patterned “zigzags”



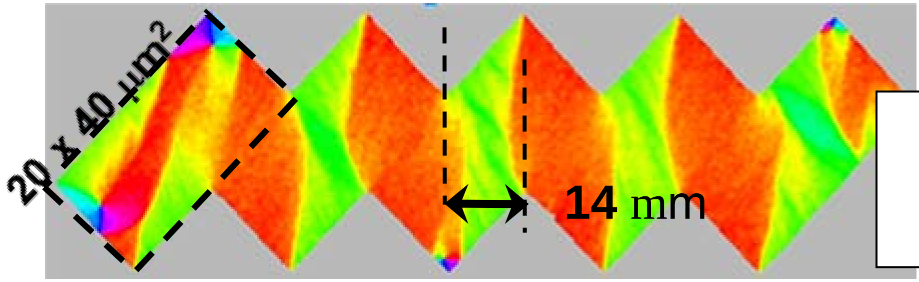
20 x 40 mm cell



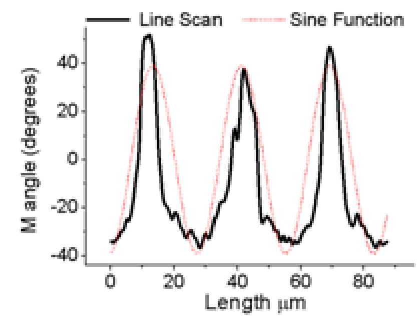
We used e-beam lithography to write patterns in 12 nm thick $Ni_{80}Fe_{20}$ films spanning over two orders of magnitude in size

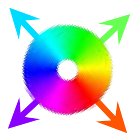
100 x 200 nm cells

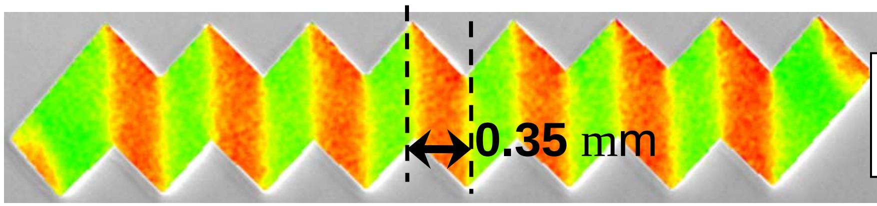
Research Program Highlight
Magnetization vs. Size – Three Regimes



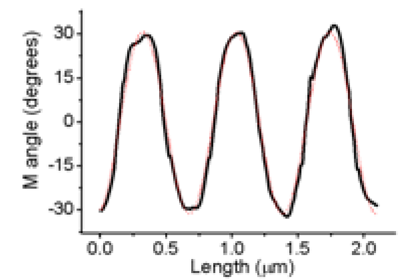
Extended Film Dominates

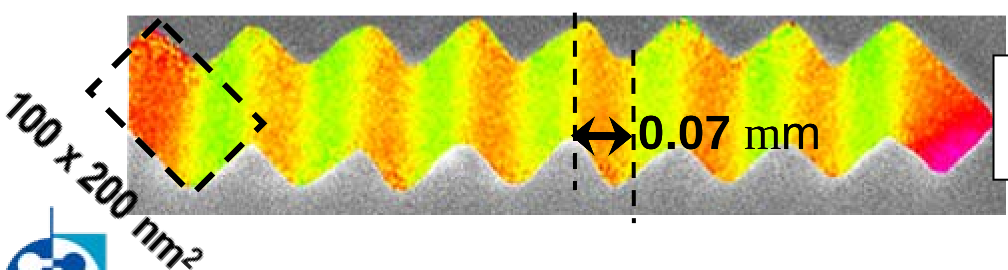




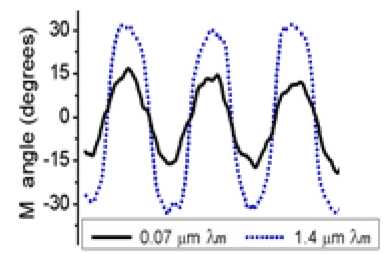


Shape Dominates

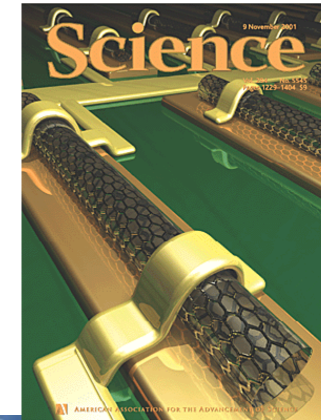


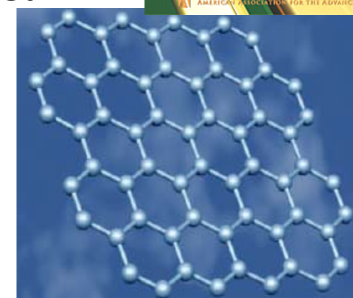


Exchange Dominates



Research Program Highlight
Carbon Based Future Electronics

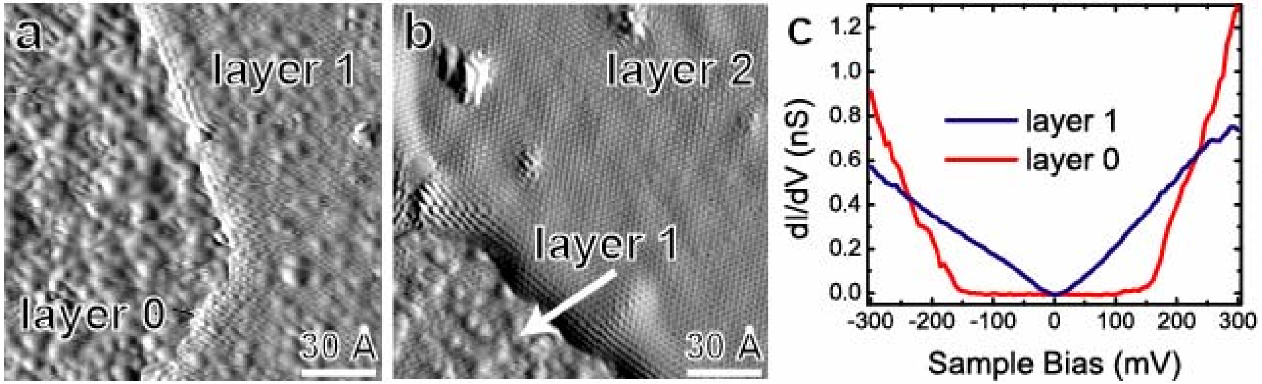




- Objective:
  - Develop technology to build electronics from single layer graphene sheets with possible integration with Si technology using SiC
  - Measure electronic properties of single layer graphene sheets grown on SiC
  - Measure transport in graphene electronic devices and correlate with microscopic properties
- Accomplishments:
  - Discovered novel imaging of the first layer of graphene using the energy dependence of the electron density of states
  - Determined defects in graphene lattice cause symmetry breaking scattering which will reduce backscattering and ballistic transport

Research Program Highlight
Carbon Based Future Electronics

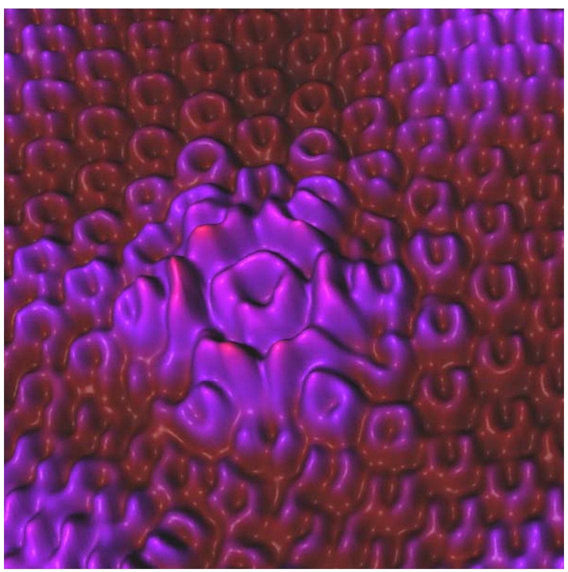
- Identification of graphene layers on SiC
  - Measurements of the local density of states provide a signature of single layer graphene.

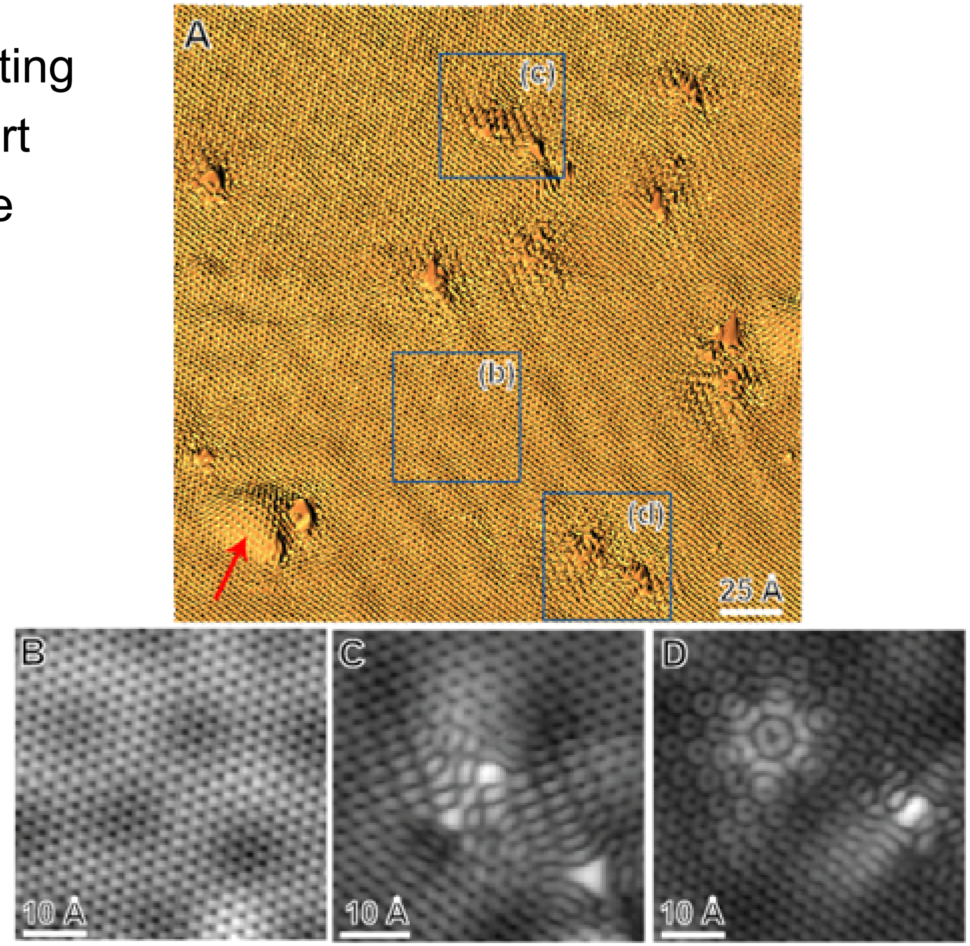


Interference and Localization in Epitaxial Graphene, G. M. Rutter, J. N. Crain, T. Li, P. N. First, and J. A. Stroscio, *Science* **317,** 219-222 (2007).

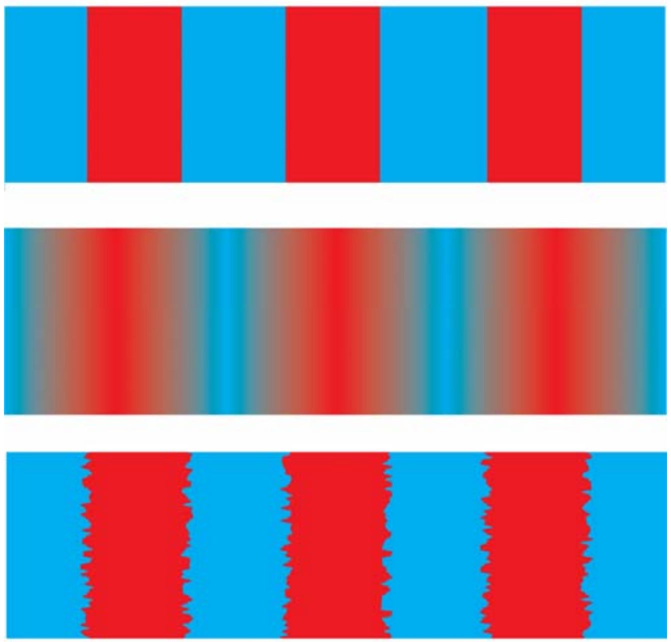
Research Program Highlight
Carbon-Based Future Electronics

- 1st layer of graphene becomes "transparent" to tunneling at energies away from E_F
- Graphite sheet bends over "supporting structure" without affecting transport
- Unknown defects in sheet do cause scattering





Research Program – New Start
Latent Image Line Edge Roughness Measurement

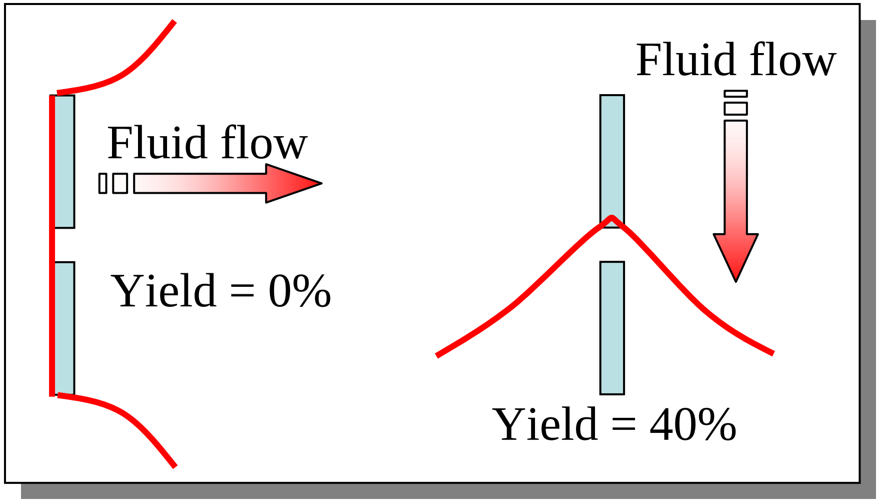


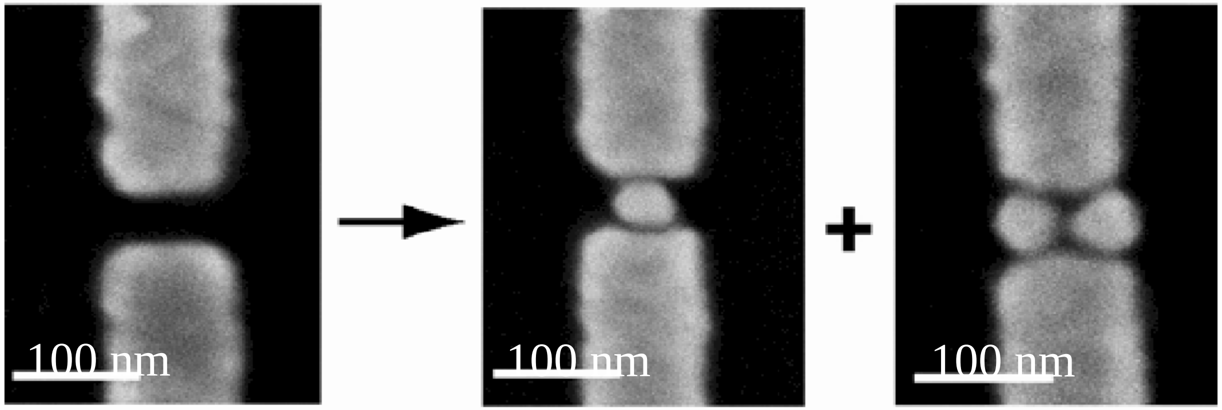
- Are interfaces sharp, chemically diffuse or rough?
- Need to know e.g. for resist in IC manufacture.

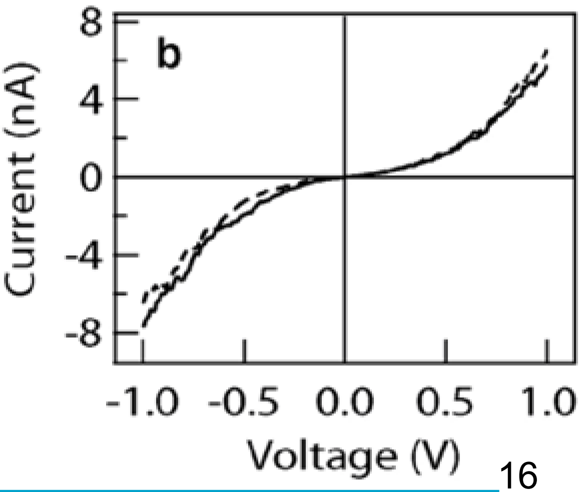
- X-ray scattering
  - currently used to measure resist feature profiles
  - but much more information is potentially available
- Resonant x-ray scattering can provide information about interfaces still within material
  - x-ray energy can be tuned to provide high contrast
  - Gives interfacial width and roughness in diblock or triblock copolymers
  - Gives latent image line-edge roughness (LER) in photoresists
- Oriented structures
  - provide an easily modeled system
  - physically relevant parameters can be obtained

Research Program – New Start
Assembly and Measurement of Nanoparticles

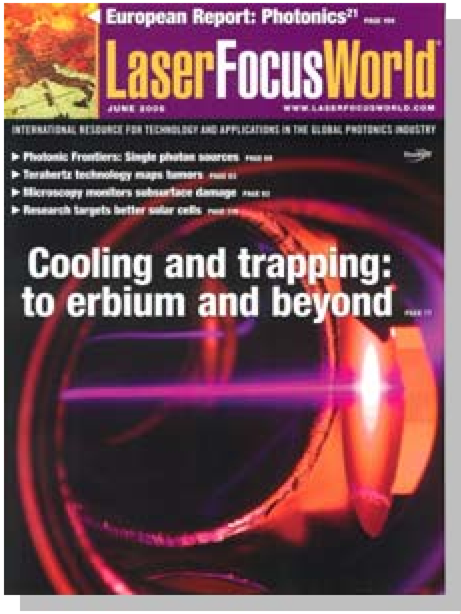
- Electrical Measurements of Nanocrystals
  - 50 nm Au particles assembled using capillary forces





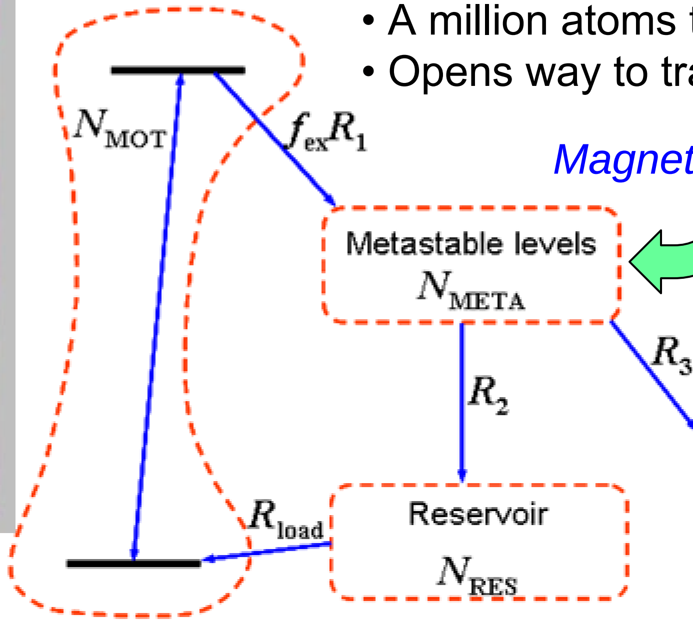


Research Program Highlight
Laser Cooling without Repumping



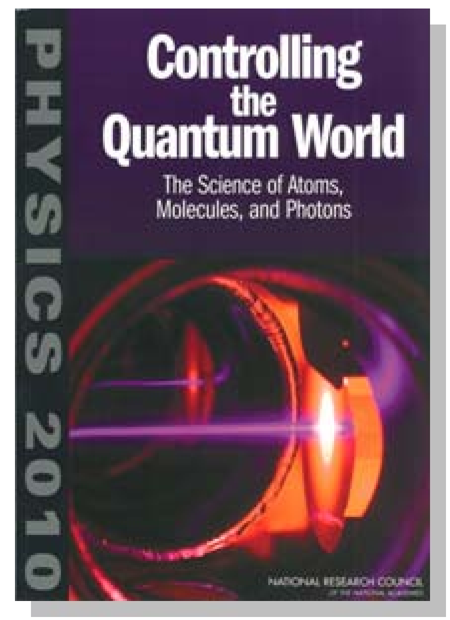
- A new recycling mechanism discovered
- A million atoms trapped despite optical losses
- Opens way to trapping many more atomic species

Magnetic field keeps these atoms in play



Why erbium?

- Single-atom source for precision doping of optical materials
- True two-level atomic system at λ = 1.3 μm for quantum optics at telecom wavelengths
- Opportunity for cooling to 80 nK
- Large magnetic moment for magnetic trapping and studying dipolar gasses



Research Program - Highlights

- Some significant publications:
  - Interference and Localization in Epitaxial Graphene, G. M. Rutter, J. N. Crain, T. Li, P. N. First, and J. A. Stroscio, *Science* **317,** 219-222 (2007).
  - Identification of the Dominant Precession-Damping Mechanism in Fe, Co, and Ni by First-Principles Calculations, K. Gilmore, Y. U. Idzerda, and M. D. Stiles, *Phys. Rev. Lett.* **99**, 027204 (2007)
  - Electronically Induced Atom Motion in Engineered CoCu Nanostructures, J. A. Stroscio, F. Tavazza, J. N. Crain, R. J. Celotta, and A. M. Chaka, *Science* **313**(5789), 948-951 (2006).
  - Electronic Effects in the Length Distribution of Atom Chains, J. N. Crain, M. D. Stiles, J. A. Stroscio, and D. T. Pierce, *Phys. Rev. Lett.* **96**(15), 156801-1-156801-4 (2006).
  - Laser Cooling without Repumping: A Magneto-Optical Trap for Erbium Atoms, J. J. McClelland and J. L. Hanssen, *Phys. Rev. Lett*. **96**, 143005 (2006).
  - End States in One-Dimensional Chains, J. N. Crain and D. T. Pierce, *Science* **307**(5710), 703-706 (2005).

Recognition

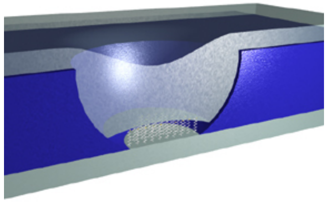
- Recent awards:
  - Nathan Guisinger, AVS 2007 Young Researcher Award 7/07
  - Joseph Stroscio elected to NIST Fellowship 7/07
  - Jason Crain, Sigma Xi Young Investigator Award 12/06
  - Jabez McClelland, DOC Gold Medal Award 12/06
  - Mark Stiles, Nanotech Briefs Nano 50 Award 9/06
  - Joseph Stroscio, Nanotech Briefs Nano 50 Award 9/06
  - Kenneth Chau, Fellowship, Natural Sciences and Engineering Research Council of Canada

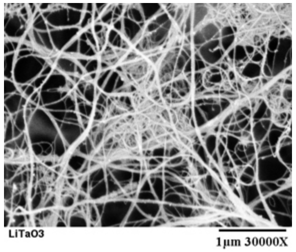
Challenges:
Some of the things we will be working on this year

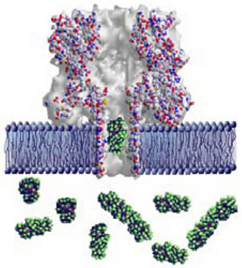
- Completing moves
  - About 15% of AML moving, but no swing space
  - Many different contracts, organizations
    - Any one of which can cause a major delay
- Outreach for optimal Nanofab utilization
  - NIST Staff
  - Outside Users
- Establishing equipment sharing paradigm at NIST
- Recruiting remaining research program staff
- Establishing an efficient team from newly hired administrative staff

NIST Nanotechnology Highlights

Highlights:





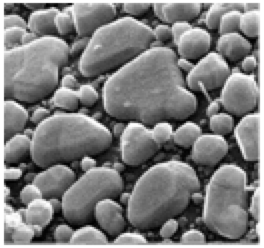


- *Molecular Spintronics*
  - *Used nanoscale pore in Si wafer*
  - *One molecule thick layer of self assembled molecules*
  - *Observed vibrational energies of molecular states*
- *Laser-based Nanotube Cleanup*
  - *Purifies raw nanotube material*
  - *Reduces carbon impurities, e.g., graphite, soot, etc.*
  - *Does not destroy tubes*
- *Nanoscale Pores Provide Analysis*
  - *Detects and sorts different sized polymer chains*
  - *Uses a lipid bilayer membrane*
  - *Pore size ~ 1.5 nm*
  - *Current flow indicates chain size*

Highlights:

Nanotech Briefs Nano50

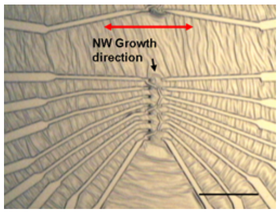
- ***Nanotechnology Research Recognized with two Nano 50 Awards***
  - ***Scanning Electron Microscopy***
  - ***Scatterfield Optical Microscopy***



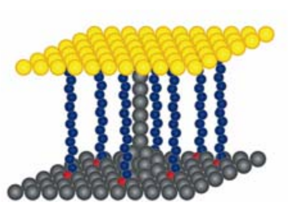
- ***First Results Reported for Helium Ion Microscopy***
  - ***New instrument has been installed***
  - ***Study of imaging process has begun***

Highlights:

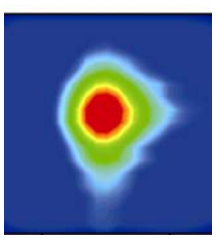
- ***Nanowire Device Fabrication Method Demonstrated***
  - ***Nanowires grown on sapphire wafer in specific locations and directions***
  - ***Gold deposits used as nucleation points***
  - ***Zinc Oxide nanowires grown to create 600 nanowire based transistors***



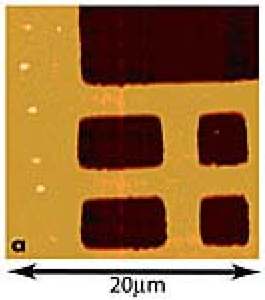
- ***Nanoelectronic Switch Demonstrated***
  - ***Uses self-assembled layers of organic molecules***
  - ***Silver atoms quickly assemble to form conduction path***
  - ***Growth provides nanoscale binary switch***



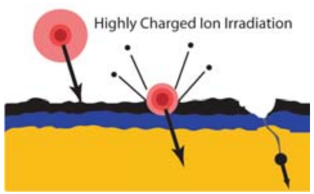
- ***SWNT Interaction with Polarized Light Studied***
  - ***DNA stretching alignment method used***
  - ***First experimental verification of optical response***
  - ***Joint with Physics Lab and RIT***



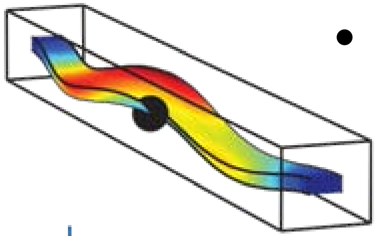
Highlights:



- **_New Hybrid Microscope Developed_**
  - _Scanning Photoionization Microscopy (SPIM)_
  - _High spatial resolution_
  - _Electrical sensitivity from low energy electron detection_

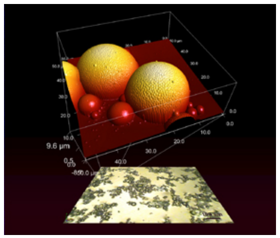


- **_Highly Charged Ions Used to Study GMR/TMR_**
  - _Insulating buffer layer modified by xenon +44 ions_
  - _Device incorporates both GMR and TMR effects_

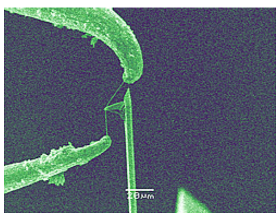


- **_High Speed Nanoscale Vibrations Measured_**
  - _The 40 MHz NEM vibrations observed_
  - _Offers potential of 500-fold increase in STM speed_

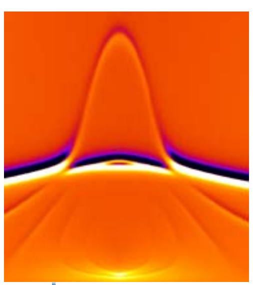
Highlights:



- ***"Fossilized Liquid Assembly"***
  - *Components self assemble freely in liquid*
  - *UV light exposure polymerizes a monomer*
  - *Allows the study of the self assembly process*



- ***Carbon Nanotube Tools***
  - *Carbon "nanoknife" stretched between two tungsten needles*
  - *Could be applied to slice individual cells*



- ***Edges of Magnetic Films Affect Properties***
  - *Important as size is reduced*
  - *Thickness and processing matter*
  - *Resonance process isolates edge response*

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and
Recent Highlights in Nanotechnology at NIST

Questions?

Robert Celotta, CNST, Acting Director

VCAT Nanotechnology Subcommittee Meeting

December 11, 2007

(For further information see: http://cnst.nist.gov)

Appendix
Strategic Planning Details

Goal: Establish the Nanofab as a world-class facility

- Action: Learn about Nanofab needs and best practices
  - Discussions were held with the leadership of:
    - The National Nanotechnology Initiative
    - The National Nanotechnology Infrastructure Network
    - The National Nanomanufacturing Initiative Network
    - The Cornell University, Stanford University, University of Pittsburg, and University of Maryland, DoE LANL/Sandia, DoE BNL, and Lucent Nanofabrication Centers
  - Visits were made to the following nanofabrication facilities:
    - DoE LBNL Molecular Foundry (visited, served on review panel, staff transferred from)
    - DoE ORNL Nanocenter (visited, staff transferred from)
    - DoE ANL Nanocenter (visited, served on panel)
    - SUNY (Albany), University of Texas (Austin), SEMATECH/ATDF, LETI (Grenoble), China (Various)
    - Nanomanufacturing Center (scheduled)

Goal: Establish the Nanofab as a world-class facility

- Action: Learn about Nanofab needs and best practices
  - Direct input was obtained from potential users
    - NIST Staff
      - Direct requests for input from entire staff
      - Established an internal user committee
      - Made a three person, 2-day visit to NIST Boulder
      - Established continuous staff/user interactions; Nanofabrication Seminar Series
    - Industrial Community
      - Had multiple interactions with Intel, IBM, Seagate, Nanoelectronics Research Initiative members, Motorola, Texas Instruments, Zyvex, FEI Inc., Semiconductor Research Corporation, Telecommunications Industry Association, Vision2020, etc.
    - Meetings
      - Proactively held discussions regarding optimal practices for Nanofab at the following meetings: AVS, EPIB&N, Nanoelectronics Research Initiative, Gordon Conferences on Nanofabrication and Nanomagnetics, Nanoforum Europe, ICN+T 2007, APS March Meeting, etc
  - Additional continuous expert advice is being obtained
    - VCAT Nanotechnology Subcommittee
    - External Individual Experts

Goal: Establish the Nanofab as a world-class facility

- Action: Attract top notch professional staff
  - Through normal attrition and expansion, added experienced process engineers who are dedicated to service

Marc Cangemi	Process Engineering, B.S. (masks)	RIT, Photronics Inc.
Richard Kasica	Material Science, M.S. (e-beam)	Bell Labs, ORNL Nanocenter
Lei Chen	Process Engineer, Ph.D. (processes)	Nanjing U., Princeton, NanoOpto
William Young	Senior Technician (vacuum)	National Semiconductor, Covega

(replaced two NIST electronics and mechanical technicians)

- Action: Develop and implement efficient user systems
  - Established new user processes
    - Security process designed to allow users site access with minimal delay
      - Building 215 & 216 venue consistent with efficient operation *and* security
    - Computer network specified to give users access to necessary resources
    - Coral computer servers programmed to permit automated tool scheduling
    - Nanofab User Forum established for rapid communication between users and staff
    - Business systems put in place that are very flexible
      - we take MasterCard (*and* American Express!)

Goal: Greatly Broaden the Scope and Capabilities of the Nanofab

- Action: Broaden the nanofabrication capability beyond CMOS
  - Specify/procure/install new capabilities
    - Bio-compatible microfluidics capability enhanced with purchase of parylene deposition system
    - Analysis and fabrication of diverse devices facilitated by the procurement and installation of a state-of-the-art focused ion beam (FIB) external to the cleanroom.
    - MEMs fabrication capability enhanced by procurement and installation of a critical point drier
    - Low temperature/damage surface cleaning facilitated by procurement and installation of a microwave plasma asher
    - Rapid photomask production enabled through procurement of a laser writer
    - Device diversity increased by procuring various wet and vapor etch stations
    - 10-nm linewidth features made more obtainable by adding e-beam resist processing stations
    - Unique atomic scale device fabrication enabled with purchase of Atomic Layer Deposition (ALD) tool

Goal: Greatly Broaden the Scope and Capabilities of the Nanofab

- Action: Increase the nanoscale measurement capability
  - Specify/procure/install new measurement systems
    - General inspection of devices and structures made available with Atomic Force and Magnetic Force Microscopes (AFM/MFM) and optical microscopes in a new facility external to the cleanroom
    - Stress measurement in films and membranes enabled with purchase of stress measurement tool
    - Rapid, in-process inspection of devices enabled with purchase of new tabletop SEM tool
    - In-process device and wafer inspection greatly improved with order of advanced AFM/MFM tool for cleanroom

- Action: Enable access to selected NIST Lab equipment and expertise
  - Explore creative win-win scenarios with laboratory programs/personnel
    - Discussions begun on best practices to make Transmission Electron Microscopy available through the Nanofab (CSTL/MSEL)
    - Specific offer made regarding He-ion microscopy (MEL)
    - Affiliated Expert program to add value to Nanofab tools is being designed

Goal: Expand the Nanofab user base

- Action: Raise NIST staff awareness of fabrication/measurement opportunities
  - Nanofabrication Seminar Series instituted
  - Nanofabrication courses planned
  - Process engineers provide free startup assistance in selected cases – in process
  - Outreach to NIST Boulder; hire postdoc to provide support – in process
  - Lab-by-Lab seminars – planned
  - Began publicizing Nanofab user accomplishments via CNST/Nanofab website and hallway displays

- Action: Increase awareness of Nanofab in external users
  - Established an active representation at many professional meetings
    - Booths and peer-to-peer conversation
    - March APS, AVS, EIPB&N, ICN+T, NRI, NSIC Program review, etc
  - Actively sought collaborations that would make use of the Nanofab (under discussion)
    - SUNY (Albany)/Vistec
    - SEMATECH/ATDF
  - Use NIST/CNST and UMD Web Sites
    - CNST Travel Grant Program
  - Established a presence on other websites and in directory listings – in process

Strategic Planning - Goals

- Nanofab
  - Establish Nanofab as a world-class facility
  - Greatly broaden the scope and capabilities of the Nanofab
  - Expand the Nanofab user base
- Research Program
  - Determine measurement needs
  - Determine major program areas
  - Determine core competence requirements
  - Recruit the best and the brightest (*who are enthused by our mission*)
  - Establish strategic partnerships
- Infrastructure
  - Establish an administrative staff configured for efficiency and agility
  - Establish and provide for continuous refinement of operational policies
  - Acquire and provision the space necessary to operate

Strategic Planning and Actualization – Research Program

- Collect Needs
  - Direct input from
    - NIST Staff
      - Direct requests for input from entire staff
      - Continuous staff interactions
    - Industrial Community
      - Had multiple interactions with Intel, IBM, Seagate, Nanoelectronics Research Initiative (NRI), Motorola, Texas Instruments, Zyvex, FEI Inc., Semiconductor Research Corporation, Telecommunications Industry Association (TIA), Agilent, etc.
    - Meetings
      - Professional society conferences: e.g., AVS, EPIBN, NRI Program Reviews, Gordon Research Conferences, Nanoforum Europe, ICN+T, APS March Meeting, etc.
      - Workshops, e.g., NIST & NNI Workshops on Nanotechnology/Nanomanufacturing, Vision2020 Workshops, etc.
    - Government Reports
      - NNI, Europe (NanoStrand), Asia
      - US Measurement System Survey
    - CNST Research Staff
      - Leading experts in their fields
  - Additional continuous expert advice is being obtained
    - VCAT Nanotechnology Subcommittee
    - External individual experts, e.g.,
      - Jeffrey J. Welser (IBM) Director, Nanoelectronics Research Initiative
      - John Randall Chief Technical Officer, Zyvex
      - Dan Herr Director of Nanomanufacturing Sciences Research, Semiconductor Research Corp
      - Donald Tennant, Director of Operations, Cornell Nanofabrication Facility
      - Sandip Tiwari, Director of the National Nanotechnology Infrastructure Network, (NNIN)

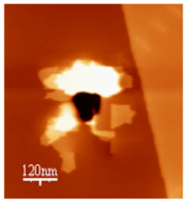
Strategic Planning and Actualization – Research Program

- Action: Select Program Areas
  - Nanotechnology is ubiquitous; we can't do everything
  - Choose areas where there are strong needs commensurate with NIST's ability to form strong programs
  - If strong programs exist elsewhere at NIST, offer our help,
    - Example: nano-bio
  - Fill voids, if possible
  - Adopt a collaboration model where NIST Labs have some existing efforts

- Action: Vet Program Areas
  - Invite 3 – 4 of the world's top experts to present a talk
    - Example: Atomic force microscopy

Some of the CNST Seminars on Atomic Force Microscopy

THURSDAY | **NOVEMBER 2, 2006, 10:30 AM — Bldg 215, Rm C103-106**

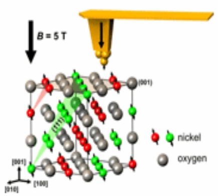


FRICTION AND PLASTICITY AT THE ATOMIC SCALE

Roland Bennewitz
McGill University, Department of Physics

High-resolution force microscopy is a tool not only for imaging surfaces with high resolution but also for measuring force and dissipation at the nanometer scale. We will discuss two examples: A study of atomic friction with high bandwidth has revealed the role of thermal fluctuations in atomic jump processes. The combination of quasi-static indentation experiments with dynamic non-contact imaging allows to study the elementary steps of plasticity. Atomic-scale yield has been correlated to the nucleation of dislocations which penetrate the surface close to the indentation point. Finally, we will generally comment on future prospects of a dissipation force microscopy with atomic resolution.

THURSDAY | **OCTOBER 26, 2006, 10:30 AM — Bldg 215, Rm C103-106**

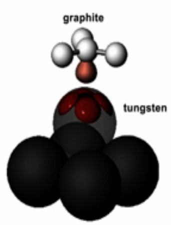


ADVANCES IN HIGH-RESOLUTION FORCE MICROSCOPY

Alexander Schwarz
University of Hamburg, Institute of Applied Physics

Over the past decade, atomic force microscopy (AFM) utilizing an oscillating cantilever and the frequency modulation (FM) technique was developed as a versatile tool to image virtually all kinds of surfaces independent of their conductivity with high resolution. Initially, it was mainly performed under ultra-high vacuum conditions in the attractive non-contact regime (NC-AFM) of the tip-sample interaction to obtain true atomic resolution. Since the snap-to-contact can be avoided in this mode of operation, the distance dependence of the tip-sample force $F(z)$ can be recorded continuously, even deep into the repulsive regime. By recording such curves on every (x,y)-image point, complete 3-dimensional force fields $F(x,y,z)$ could be acquired with atomic resolution.
Due to the high Q-values in vacuum, this technique has also increased the sensitivity of magnetic force microscopy (MFM), which detects the long-range magnetostatic tip-sample interaction. The most recent breakthrough is the demonstration of magnetic exchange force microscopy (MExFM). It combines the high magnetic sensitivity of MFM with the atomic resolution capability of AFM to image the arrangement of the magnetic moments at surfaces via the short-range magnetic exchange interaction between tip and sample spins.

TUESDAY | **OCTOBER 3, 2006, 10:30 AM — Bldg 215, Rm C103-106**



ATOMIC FORCE MICROSCOPY - STM'S COMPANION THAT SEES THE OTHER ELECTRONS - AND SOMETIMES SHARPER!

Franz J. Giessibl
University of Regensburg, Institute of Experimental and Applied Physics

The STM has rapidly found its place in most surface science laboratories as a tool to obtain atomically resolved images of conductive samples. Obtaining atomic resolution by Atomic force microscopy (AFM) took almost a decade because of the special challenges faced by AFM with respect to STM AFM is a method that now allows to routinely image conductive and insulating surfaces with atomic resolution. One of the challenges faced by AFM researchers originates in the physics of measuring the small forces that act between the tip of a force sensing cantilever and the sample. Frequency modulation AFM, where the cantilever's oscillation frequency is used to determine the forces acting between tip and sample is the method of choice for atomic AFM imaging as frequency measurements are among the most precise physical measurements possible. Early measurements used silicon cantilevers with a stiffness of k 20 N/m and oscillation amplitudes of A 10 nm. From 1999, we used cantilevers made from quartz with k approx. 2 kN/m with sub-nm amplitudes. The stiff cantilever/small oscillation amplitude allows imaging at much smaller tip-sample distances which greatly improves spatial resolution. Even greater resolution can be obtained by monitoring the higher harmonics that occur when a cantilever vibrates in a non-harmonic tip-sample potential, and the simultaneously recorded STM signal shows much less contrast (Fig. c). If forces and currents were proportional or related by power laws, we would expect to see similar images in combined STM/AFM experiments, but experimentally we find large differences in some cases. This could be explained by the energy range of the electrons that are involved in tunneling currents and forces - STM only probes electrons at the Fermi level, while the bonds that form in AFM operation may involve lower energy states as well.

Strategic Planning and Actualization – Research Program

- Action: Select Program Areas
  - Nanotechnology is ubiquitous; we can't do everything
  - Choose areas where there are strong needs commensurate with NIST's ability to form strong programs
  - If strong programs exist elsewhere at NIST, offer our help
  - Fill voids, if possible
  - Adopt a collaboration model where NIST Labs have some existing efforts
- Action: Vet Program Areas
  - Invite 3 – 4 of the world's top experts to present a CNST Seminar
    - Follow with a 2 hour interview session to answer such questions as:
      - What are the measurement problems in this field
      - What are the scientific and technical opportunities
      - Who are the best and the brightest *measurement science oriented* researchers available today
  - No US Citizens qualified!
    - Jason Crain comes to the rescue!
    - International collaboration with EMPA (ETH-Zurich) formed to develop the next generation atomic force microscope

EMPA Materials Science & Technology

Strategic Planning and Actualization – Research Program

- Program Areas Selected
  - **Future Electronics**
    - Devices, architectures, interconnects
  - **Nanomanufacturing and Nanofabrication**
    - Top-down and bottom-up fabrication and assembly
  - **Energy**
    - Conversion, storage, and transport

CNST Technical Hires

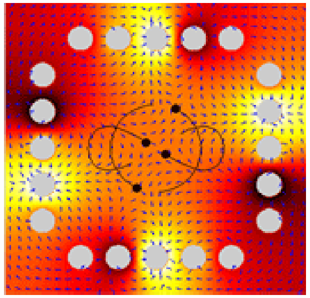
• Andrew Berglund.	Physics, Ph.D.	Caltech
• Marc Cangemi*	Process Engineering, B.S.	RIT; Photronics
• Peter Carmichael	Bio-Chemistry	UCSD; UT Austin
• Kenneth Chau	Elect. & Comp. Eng., Ph.D.	University of Alberta
• Lei Chen*	Polymer Sci. & Eng., Ph.D.	Nanjing Univ.; Princeton; NanoOpto
• Seok-Hwan Chung	Physics, Ph.D.	University of Maryland; ANL
• Nathan Guisinger	Physics, Ph.D.	University of Illinois
• Paul Haney	Physics, Ph.D.	University of Texas, Austin
• James Hanssen	Physics, Ph.D.	Rice University
• Christian Heiliger	Physics, Ph.D.	Martin Luther University, Halle
• Emily Jarvis	Chemistry, Ph.D.	UC Los Angeles
• Suyong Jung	Physics, Ph.D.	University of Texas, Austin
• Richard Kasica*	Material Science, M.S.	Bell Labs; Oak Ridge NL
• Henri Lezec	Electrical Engineering, Ph.D.	MIT; CNRS (Strasbourg); CalTech
• Alex Liddle	Materials Science, Ph.D.	Oxford; Lawrence Berkeley NL
• Matthew McMahon	Physics, Ph.D.	Vanderbilt University
• Sander Otte	Physics, Ph.D.	University of Leiden, IBM (Almaden)
• Gregory Rutter	Physics, Grad Student, B.S.	Georgia Tech
• Young Jae Song	Physics, Ph.D.	Seoul National University, Seoul
• Kartik Srinivasan	Physics, Ph.D.	CalTech
• Gila Stein	Chemical Engineering, Ph.D.	UC Santa Barbara
• Nikolai Zhitenev	Physics, Ph.D.	Institute of Low Temperature Physics; Max-Plank-Institute Stuttgart; Bell Labs

Strategic Planning and Actualization – Research Program

- Action: Establish strategic partnerships
  - NIST
    - MSEL (Nanomagnetics; thin film nanostructure)
    - MSEL (Bistable-switch)
    - EEEL (Nanomagnetics; low noise sensors)
    - EEEL (Theory; magnetization dynamics)
    - ITL (Nanomagnetics; domain properties, wall motion)
    - CSTL (Atomic Scale Measurement; atom switching dynamics)
    - MEL (Probe Measurements; beam probe analysis)
    - PL, MSEL (Nanofabrication; particle assembly)
    - PL, MSEL (Nanofabrication; edge roughness)
  - NIST (under consideration or development)
    - NCNR (Nanofabrication; edge roughness)
    - EEEL (Nanofabrication; photonic couplers to bolometers)
    - EEEL, CSTL, PL (Optical communication; FY2009 initiative)
  - UMD
    - Aerospace Engineering (Control System Theory/Application)

Using Flexible Staffing Arrangements

THURSDAY **JULY 26, 2007, 10:30 AM — Bldg 215, Rm C103-106**



ON CONTROL OF MICRO-SCALE SYSTEMS: COMBINING MODELING, CONTROL, SENSING, AND ACTUATION TO ACHIEVE NEW CAPABILITIES

Benjamin Shapiro
Aerospace Engineering Department, University of Maryland

Modeling, design, and control of micro-scale devices for bio-chemical and medical applications. The focus is on applications where control can dramatically improve or allow new system capabilities. We consider all aspects of the design pathway from initial application choice, to system modeling, device fabrication, phrasing of design tasks as tractable mathematical problems, control algorithm development, and experimental demonstration and validation. Projects include steering of cells by micro flow control, precision control of electrowetting flows, modeling and control of bio-compatible conducting plastic micro-actuators, monitoring cells on chip, and magnetically targeted deep-tissue drug delivery.

Strategic Planning and Actualization – Research Program

- Action: Establish strategic partnerships
  - External
    - FEI Inc. (Nanofabrication; Focused Ion Beams)
    - Colorado State University (Future Electronics; Atom Based Metrology)
    - Gordon College (Future Electronics; proximal probe analysis)
    - Montana State University (Future Electronics; energy dissipation in nanostructures)
    - John Hopkins University (Future Electronics; magnetic nanocontacts)
    - Texas A&M (Future Electronics; magnetization dynamics)
    - EMPA Zurich (Nanofabrication; force microscopy)
    - Princeton University (Future Electronics; spintronics)
    - Georgia Tech, Intel (Future Electronics; electronic nanomaterials)
    - Georgia Tech (Future Electronics; magnetization dynamics)
    - Cavendish Laboratory, Cambridge (Future Electronics; domains in nanostructures)
    - MIT (Future Electronics; domains in nanostructures)
    - University of Houston (Future Electronics; patterned media)
    - Hitachi Global Systems (Future Electronics; nanoscale read heads)
    - Intel (Future Electronics; LSMO future logic)
    - Army Research Laboratory (Future Electronics; MEMs based magnetic sensors)
    - University of Illinois (Chicago) (Future Electronics; nanoscale cellular atomata)
    - Carnegie Mellon University (Future Electronics; multiferroics)
    - Geological Survey of Norway (Geomagnetism)
    - Advanced Microsensors (Future Electronics; nanoscale read heads)
    - IBM Yorktown Research Center (Future Electronics; MRAM)

Strategic Planning and Actualization – Research Program

- Action: Establish strategic partnerships
  - External (under consideration or development)
    - SEMATECH / ATDF (Nanofabrication, e-beam processing)
    - SUNY Albany / Vistec, MEL (Nanofabrication; probe measurements)
    - CalTech (Nanofabrication; nanophotonic probes)
    - Los Alamos / Sandia (Future Electronics: fast nanophotonics)
    - Purdue/Hummingbird (Nanofabrication; nanoscale actuators in TEMs)
    - Bell Labs (Future Electronics; SET Microscope for subsurface imaging)
    - University of Sciences, Philadelphia, MSEL (Future Electronics; bistable switch)
    - Naval Research Laboratory (Future Electronics, electrical probe of biomolecules)
    - UC Berkeley (Nanofabrication; masks for directed assembly)
    - University of Wisconsin (Nanofabrication; AFM probes)
    - Janelia Farms (Novel bio-imaging)
    - IBM Almaden (Future Electronics, magnetic hippodrome)

Action: Establish strategic partnerships – A high visibility example

Economist.com

SCIENCE & TECHNOLOGY

Data storage

A magnetic hippodrome

May 10th 2007
From The Economist print edition

How to record a memory on a wire

HARD disks dominate the field of computer memory. They store oodles of information—which is why they are so useful. But they are also slow, heavy and power-hungry. Unfortunately solid-state memories, such as flash, that do not have these disadvantages are too expensive for stashing the vast programs needed to run a modern computer. What engineers would like is a device that combines the best of both. And a group of them have now taken a step towards developing such a piece of kit—a magnetic memory with no moving mechanical parts.

The idea began a few years ago when Stuart Parkin, who works at IBM's Almaden Research Centre in San Jose, California, worked out how to use a wire to store

Strategic Planning and Actualization – Reprogramming

- Action: Reprogramming experimental research
  - Room-temperature Scanning Tunneling Microscopy research ➔ Development of the Next Generation Atomic Force Microscope (AFM)
  - Mature technology; resources better allocated elsewhere
    - Jason Crain, Project Leader ➔ NextGen AFM Program as Project Leader
    - Dan Pierce, NIST Fellow ➔ Nanomagnetics Project
    - STM Equipment ➔ Routine analysis support of molecular beam epitaxy lab
    - Vibration controlled lab space ➔ Refitting for NextGen AFM Project
    - International collaboration formed to provide needed skill set and supercritical mass

- Action: Reprogramming theoretical research
  - Theory of magnetic multilayers ➔ Theory of proximal probe measurement
  - Essential physics appears captured; theory analysis better applied elsewhere
    - Mark Stiles, Project Leader ➔ Proximal Probe, Project Leader
    - Post doctoral research focus changed at normal replacement cycle
    - Additional computer resources added to support the new task

Strategic Planning - Goals

- Nanofab
  - Establish Nanofab as a world-class facility
  - Greatly broaden the scope and capabilities of the Nanofab
  - Expand the Nanofab user base
- Research Program
  - Determine measurement needs
  - Determine major program areas
  - Determine core competence requirements
  - Recruit the best and the brightest (who are enthused by our mission)
  - Establish strategic partnerships
- Infrastructure
  - Establish an administrative staff configured for efficiency and agility
  - Establish and provide for continuous refinement of operational policies
  - Acquire and provision the space necessary to operate

Strategic Planning and Actualization – Infrastructure

- Action: Establish an administrative staff configured for efficiency and agility
  - Adopted a structure similar to that of NCNR
  - Investigating most effective use and support of IT
    - Planning with OCIO's staff
  - Investigating most effective knowledge management strategies
    - Planning with TS Research Services Division
    - Center office structured with knowledge management specialist
  - Initial administrative positions are either being advertised or filled

- Action: Establish and provide for the continual improvement of operational policies
  - Established full procedures and policies necessary to begin operation of the Nanofab, a national user facility on May 1, 2007
  - Daily processes in CNST follow a constantly updated Operations Manual (a Wiki with adult supervision)

Strategic Planning and Actualization – Space

- Action: Acquire and provision the space necessary to operate
  - Under the direction of Jim Hill and Robert Moore and coordinated with CNST
    - A set of policies and processes was established
    - Responsibilities were determined
    - Financial assistance was provided to significantly disrupted projects
    - A overall timetable was set
    - A complex process of moves was scheduled and contracts were let
    - The first moves have begun
    - All non-CNST moves to be complete this fiscal year
    - New CNST staff is being “doubled or tripled up” in legacy labs temporarily and compressed in offices permanently